CONFIDENTIAL

April 19, 2012

Plug-in Electric Vehicle Technology Overview

Nick Nigro

Executive Workshops on Strategies and Best Practices for State Departments of Transportation to Support Commercialization of Electric Vehicles and Infrastructure

CENTER FOR CLIMATE AND ENERGY SOLUTIONS

C2ES.ORG

Overview

- **Understanding PEV technology is the key to making smart regulatory and investment decisions**
- **Vehicle Technology**
  - All kinds of PEVs: BEVs, PHEVs, and EREVs
  - Drivetrains, system efficiency, and batteries
- **Charging Technology**
  - Charging levels – charging needs and standards definition
  - Advanced technology – wireless, battery swapping

Vehicle Technology

PEVs are a transformative opportunity that presents a true alternative to the internal combustion engine

PEV Alphabet Soup

Plug-in Electric Vehicle (PEV)

A vehicle that can be powered by a rechargeable battery pack and connects to the electrical grid

Battery Electric Vehicle (BEV)

- Electric drive vehicle that can only be powered by a battery pack

Extended Range Electric Vehicle (EREV)

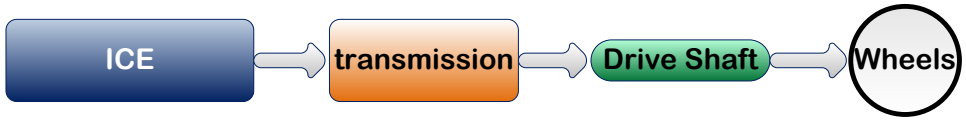
- BEV with a backup internal combustion engine powered by gasoline, biofuel, etc. (a.k.a. range extender)

Plug-in Hybrid Vehicle (PHEV)

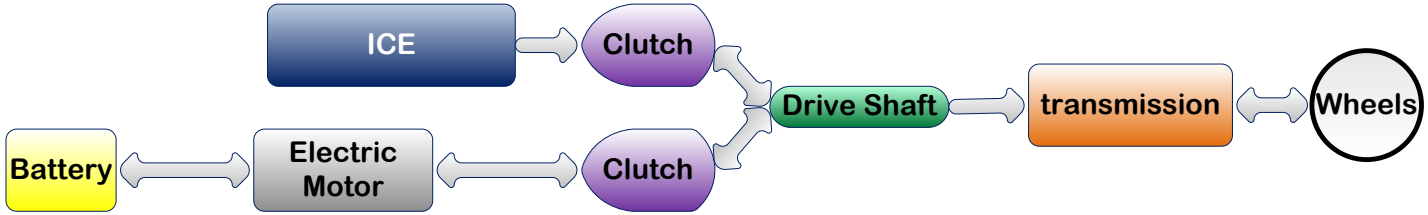
- Electric and conventional drivetrain in one
- Similar to a Prius with a larger battery pack that can be recharged

Vehicle Powerflows

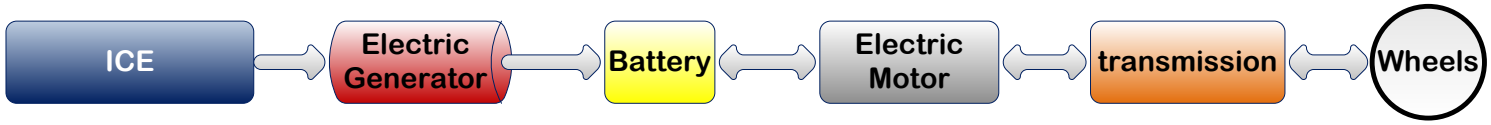
Conventional ICE Powerflow



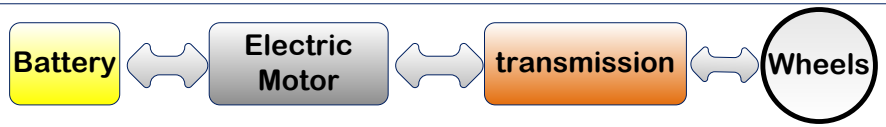
(Plug-in) Hybrid Electric Parallel Powerflow (e.g., Toyota Prius)



(Plug-in) Hybrid Electric Series Powerflow (e.g., Chevy Volt)



Battery Electric Vehicle



Source: C2ES PEV Literature Review

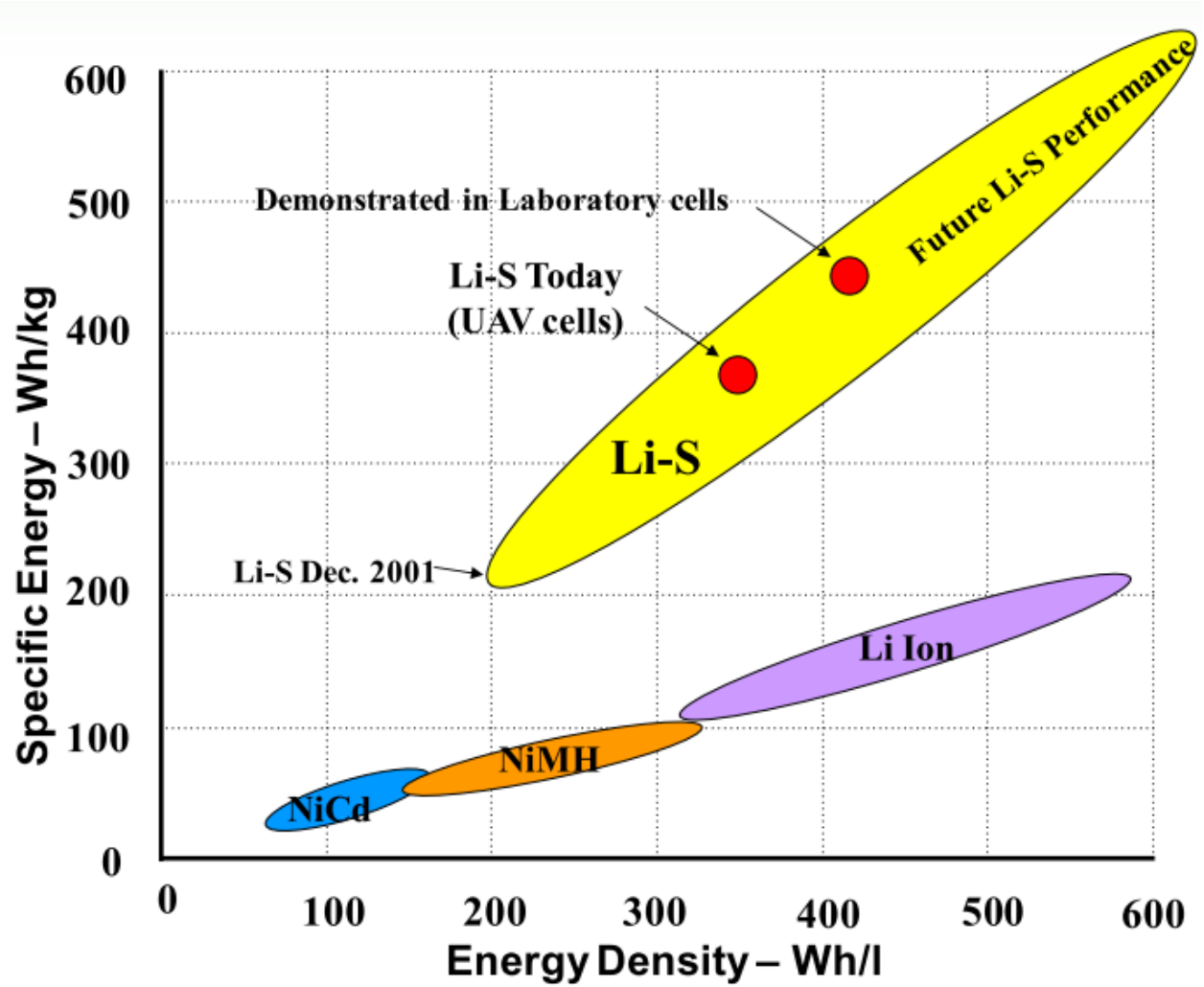
Vehicle System Efficiency

VEHICLE TYPE		ENERGY DENSITY (WH/KG)	SYSTEM EFFICIENCY	SYSTEM LEVEL ENERGY DENSITY (WH/KG)
TODAY	Conventional Vehicle * (Gasoline)	13,000	21%	2,730
	PEV** (Lithium Ion Battery)	100-250	81%	81-203
FUTURE	Conventional Vehicle*** (Gasoline hybrid)	13,000	42%	5,460

* Includes energy loss from internal combustion engine, standby/idle, driveline, and accessories.
** 10% energy loss from electric motor and 10% loss from battery charging. Does not include loss from accessories.
*** Assume doubling of efficiency through advanced drivetrains, engine shut-off when idle, regenerative braking, and more.

Source: C2ES PEV Literature Review

Advancements in Battery Technology



Source: U.S. DOE's ARPA-E Program

Lead Acid (not shown): Used in first GM EV1

NiMH: Used in final version of GM EV1; Gen 1 and 2 Prius

Li-ion: Used in PEVs today

Envia Systems announced a 400 Wh/kg Li-ion battery in 2/2012

Vehicle Range

- **Electric-only range varies widely**
  - E.g., Nissan LEAF range can vary from 60 miles to over 100 miles
- **Range is a function of driving conditions, driver behavior, vehicle system efficiency, battery size**
- **Factors that affect driving range:**
  - Mostly, the same things that affect conventional vehicle fuel economy
  - Climate control, hills, aggressive driving, regenerative braking, etc.

Charging Technology

Vehicle “refueling” with and without a plug

Understanding Charging Needs

Low – AC 120V

- Uses standard outlet
- Power requirements: ~ space heater
- Adapter comes with the car
- Accommodates average daily driving needs
- Very low cost installation, often free

Medium – AC 240V

- Requires high-voltage circuit
- Power requirements: ~ clothes dryer
- Charging stations can cost about $500
- Installation costs vary widely (~$1,500)

High – DC Fast Charge

- Requires very high voltage circuit
- Power requirements: ~ up to 100 homes
- No common standard for all PEVs
  - Japanese standard used by Nissan and Mitsubishi
  - SAE standard still being developed
- Very high installation cost (~$100k)
- Equipment costs vary widely

Vehicle Charging Standards

- **SAE Charging Levels**

Level	Nominal Operating Voltage (V)	Max Rated Current (A)	Max Rated Power (kW)	Mileage Rate (miles/hour)**
AC Level 1	120	12/16	1.4/1.92	4.2/5.8
DC Level 1*	200-450	80	36	108
AC Level 2	240	80	19.2	57.6
DC Level 2*	200-450	200	90	270

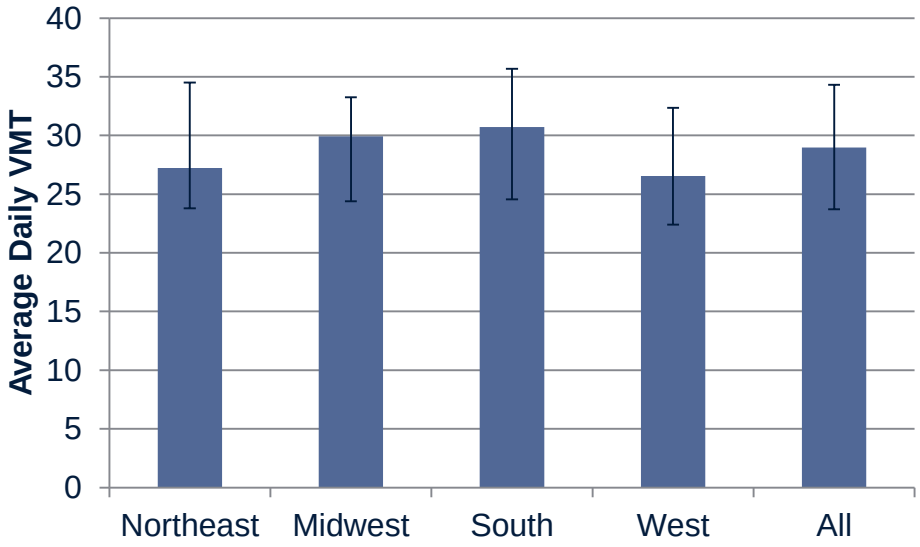
* SAE DC fast charging connector not finalized yet,

** Assumes 3 miles per kWh; actual results depends on battery characteristics

- **CHAdeMO connector for DC fast charging available for Japanese-manufactured PEVs *only***
- **Tesla has their own DC fast charging connector**

Factors Affecting Charging Needs

- **Charging needs largely depend on daily VMT**



Source: National Household Travel Survey

- **E.g., Max miles per day with AC Level 1**
  - 40 miles/day ÷ 3 miles/kWh ÷ 10 hours/day = 1.33 kWh

Refueling Without A Plug

- **Better Place: battery swap robots are real**
  - Raised almost $1b in venture capital
  - Model like mobile phone plan (pay per mile); Better Place owns the battery
  - Charging infrastructure deployed in Hawaii (government-supported)
  - Renault (Nissan) builds an EV with a removable battery
  - Battery swap stations installed or under construction in Israel, China, & Netherlands; pilot project in San Francisco with taxi cabs getting started
- **Wireless charging**
  - Uses magnetic fields to send power wirelessly (can be very efficient)
  - Parked – Several working on wireless charging while parked
  - On the move – Stanford working on system to charge while driving

PEV Technology Summary

- **Advancements in battery technology fueled PEV resurgence**
- **Auto companies have invested billions of dollars in electric drive technology**
  - All major automakers have plans to introduce PEVs within 2 years
  - They see PEVs as a long-term play
- **Charging needs vary by driving pattern**
- **Coalescing around charging standards is critical to avoid stranded assets**

CENTER FOR CLIMATE
AND ENERGY SOLUTIONS

FOR MORE INFORMATION

C2ES.ORG

nigron@c2es.org